URBAN HEAT ISLANDS FROM HIGHWAYS

Advancing city planning and design with support of the 15-minute city concept to reduce climate change negative effects.

ABSTRACT:

Buildings and urban density have been historically blamed for Urban Heat Island (UHI) contribution. This article dissents that common knowledge, deducting that main drivers of urban heat islands (among other community health indicators) are strongly correlated to highway-dominant environments.

This article looks at 4 cities in Asia: Jakarta, Singapore, Ahmedabad and Nashik; exploring a better understanding of its urban morphology, which allowed our team to understand the level of influence of Buildings, Urban Design and Morphology have into urban heat island contribution.

The present research was conducted as part of the initiative A Third Way of Building Asian Cities led by UNICITI. The initiative's mission is to help rapidly growing Asian cities unlock their unique socio-economic and sustainability potential. It aims to identify a viable alternative to the conventional uniform one-size-fits-all today's infrastructure development. This alternative approach needs to reconcile two major imperatives: the imperative for building fast and affordable and the imperative for building sustainable and livable urban infrastructure. To do so, it combines the strengths of each city's unique local context with the upscaling power of cutting-edge technologies, know-how and processes. Launched at the 55th ISOCARP Planning Congress in Jakarta, the program is undergoing Phase 1 focused on research to identify alternative building materials and construction techniques, alternative urban development models, and alternative policies and regulations. This research is supported by an International Working Group of Experts (IWGE) and by over 80 Volunteers of Change from over 35 countries.

The team is led by International Expert Julio Carrillo, AICP, LEED AP ND under Component 2, which tackles identifying and mainstreaming alternative urban development models at scale. Carrillo's team is looking into ways to integrate and balance the built and natural environment. Through data and geospatial analysis, this team dives into the statistics and spatial correlations between buildings and their surroundings. The team looks at building compactness (not a measure of density), highway corridors, diversity in land use and urban temperatures.

The findings from this team and program will be used to identify typical city development patterns in Asian cities, to guide future development in terms of policy, planning, and design, for further alignment with sustainability and livability objectives.

The members (young professionals and volunteers) of this team were:

Sneh Salot, Nisarg Thanki, Nitish Zurmure, and Valeria Cerpa.

This analysis looked at 2 different indicators of urban morphology: building compactness and land use diversity; and also looked at 2 different indicators associated with materials and surface temperatures: UHI index and Albedo index. All of these indicators were obtained and compared at a human scale, based on the concepts of a 5-min walk distance, and the 15-min city.

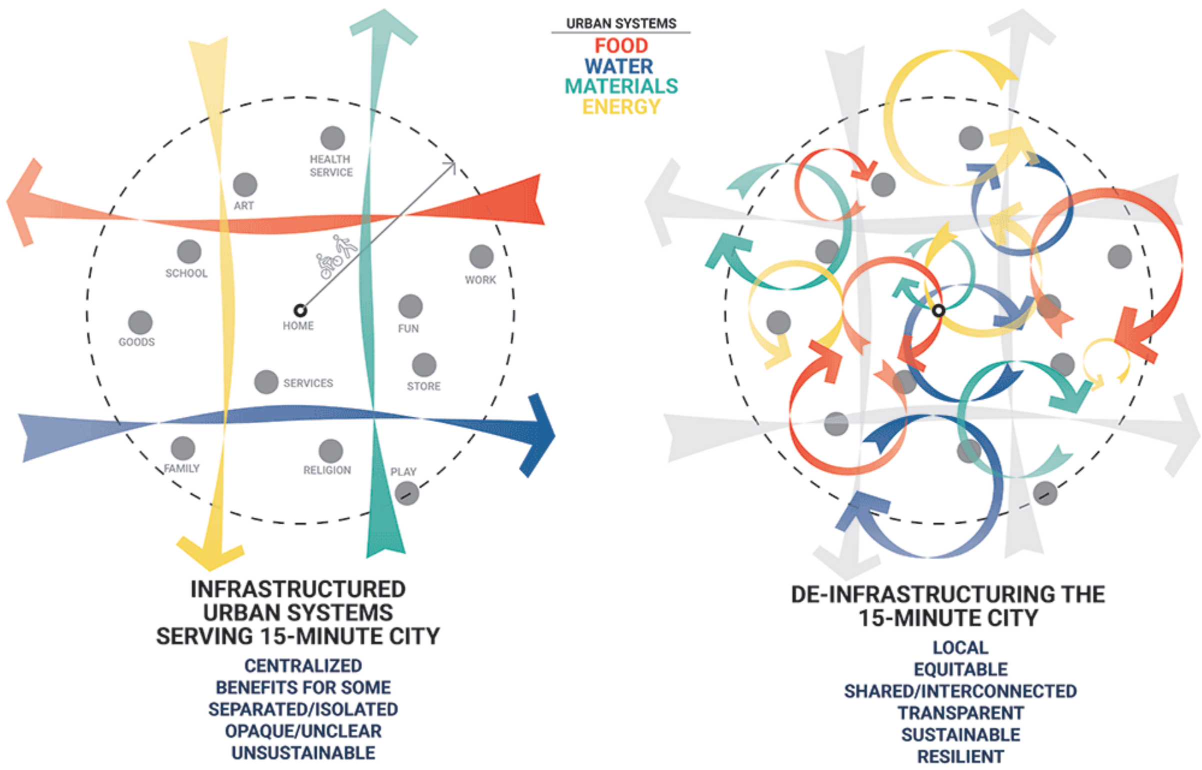


Image from De-Infrastructuring in the Era of the 15-Minute City - Urban Land Magazine, Urban Land Institute.

The statistical study from these 4 cities in Asia, and its variables, deduced the following breakthrough: Urban Heat Island's main contributor is the Open Space, with highway-dominant environments likely contributing the most to temperature increases.

This analysis helps visualize the main drivers of urban heat island contribution. This breakthrough is of vital importance for future design of transportation corridors, and its potential value when retrofitting them.

As important as the breakthrough is the process and methodology using a Systems-Thinking approach and Geospatial data analysis for urban planning and urban design. This type of approach is undoubtedly becoming increasingly important for processes in diverse professions of the built environment. Decision making based on evidence deducted from statistical analysis should be integrated in policies around the world in the process of building cities, facilitating a list of indicators to which designs should comply in terms of performance, but also for existing infrastructure that has the potential to be retrofitted.

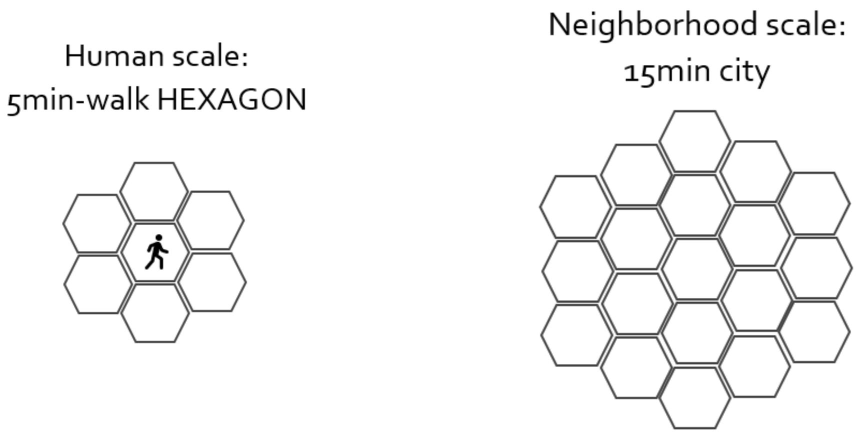
DATA MINING & METHODOLOGY

Data collection and curation was key in this analysis. Most data in Asian cities is surprisingly not available in open sources, which made our work extremely challenging, incorporating a layer of complexity to answering simple questions. Our data collection focused on curating and resampling four variables:

- Urban Heat Island Temperature (UHI),
- Albedo Index (Alb_Index),
- Land Use Diversity (LUDiv), and
- Building Compactness (BC).

As our team collected datasets, and proceeded to analyze them, it became clear that the scale for all these datasets were needed to be uniform, so that a human-scale comparison was truly performed.

Our human scale was based on the 15-min city concept. Our team decided to scale all data into a comparable size represented by an hexagon which is proportionally sized to extend a 5 minute walk between opposite edges. This way a group of 3 hexagons are approximately a 15-min walk.

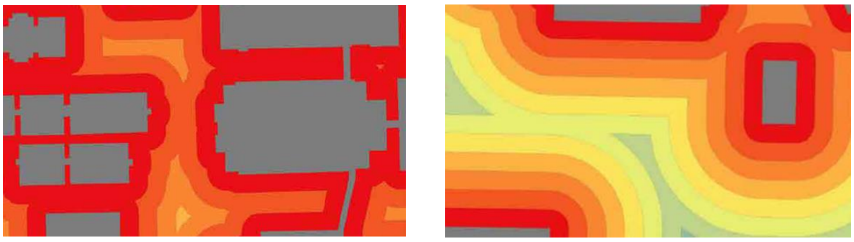


With all data curated and converted to the same scale (5-minute walk hexagon), we were able to proceed on resampling and scoring of the 4 mentioned variables: UHI, LUDiv, Alb_Index, and BC.

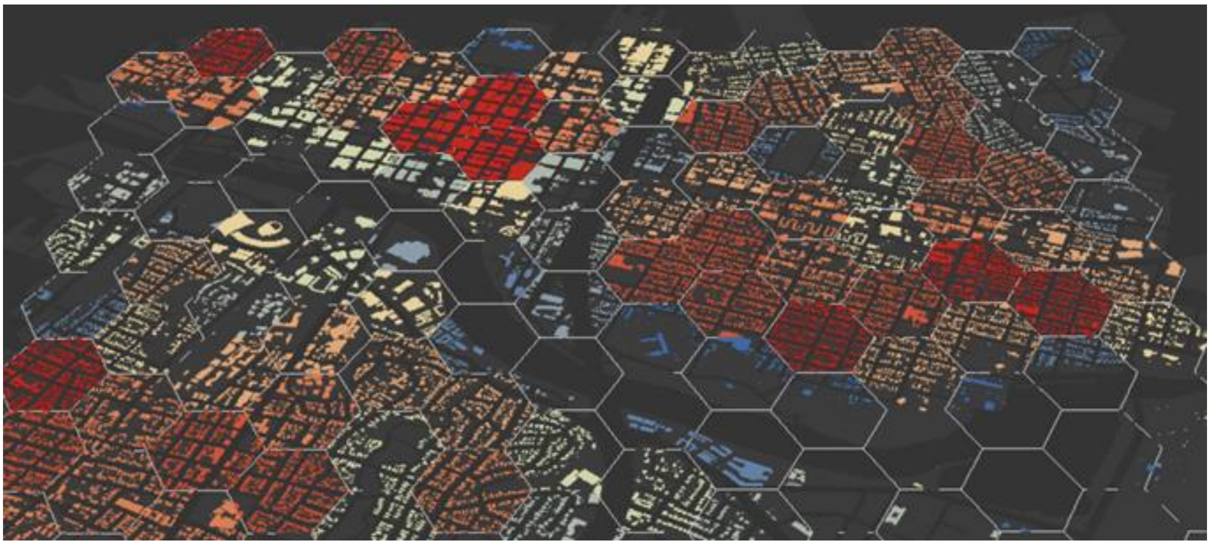
A set of grids of hexagons (aka "tessellate") was generated for each of the 4 cities in this study: Nashik, Singapore, Ahmedabad, and Jakarta. With these grids in place, temperature data analysis and urban morphology scoring was performed.

Over 2,080 data points (hexagons) were generated that collected the information of the 4 variables listed above. These were all in units comparable and relevant to the study:

- Urban Heat Island Temperature (UHI) → Temperature differential in celsius degrees for the urban clusters listed.
- Albedo Index (Alb_Index) → Index values from 0 to 1 representing the level of reflection of solar radiation.
- Land Use Diversity (LUDiv) → A result from statistical standard deviation of values in 5 main land use categories: residential, commercial, institutional/office, nature, and other.
- Building Compactness (BC) → Not a measure of density, but rather a measure of proximity and clustering of building footprints. A result from statistical standard deviation of areas within proximity rings surrounding building footprints.



Images from: Compact Campuses Help Save Money in Higher Education Institutions, by Julio Carrillo, Dec 2020 -- https://parkhill.com/insights/Compact-Campuses/



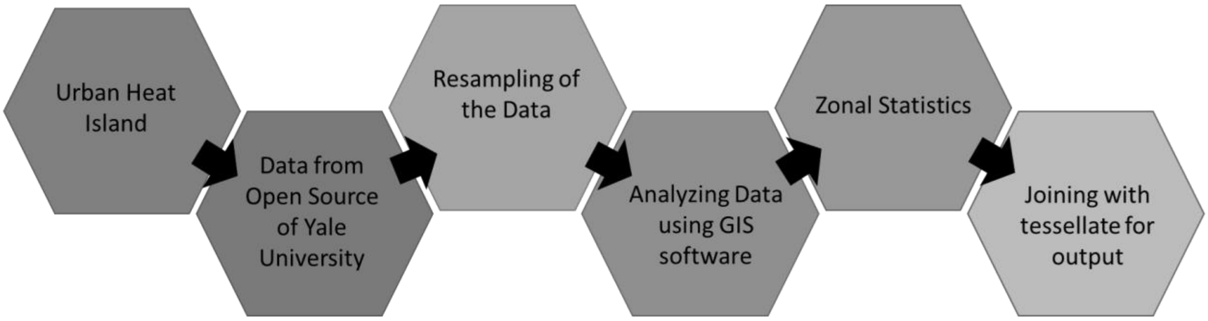
Example of building compactness in Austin, Texas - This image shows building footprints with colors related to each of the values per hexagon ("tessellate") area. Low compactness = blue, High compactness = red. Scale of colors from blue to red with 10 natural breaks.

TEMPERATURE DATA

Urban heat island (UHI) is one of the most evident local climate phenomena in urbanized areas. An urban heat island occurs when a city experiences much warmer temperatures than nearby rural areas. The difference in temperature between urban and less-developed rural areas has to do with how well the surfaces in each environment absorb and hold heat. Urban heat islands are one of the easiest ways to see how human impact can change our planet. After all, sidewalks, parking lots and skyscrapers wouldn't exist if humans weren't there to build them. And although these structures are essential to city living, the heat islands they create can be dangerous for humans.

First, materials such as asphalt, steel, and brick are often very dark colors—like black, brown and grey. A dark object absorbs all wavelengths of light energy and converts them into heat, so the object gets warm. In contrast, a white object reflects all wavelengths of light. The light is not converted into heat and the temperature of the white object does not increase noticeably. Thus, dark objects—such as building materials—absorb heat from the sun.

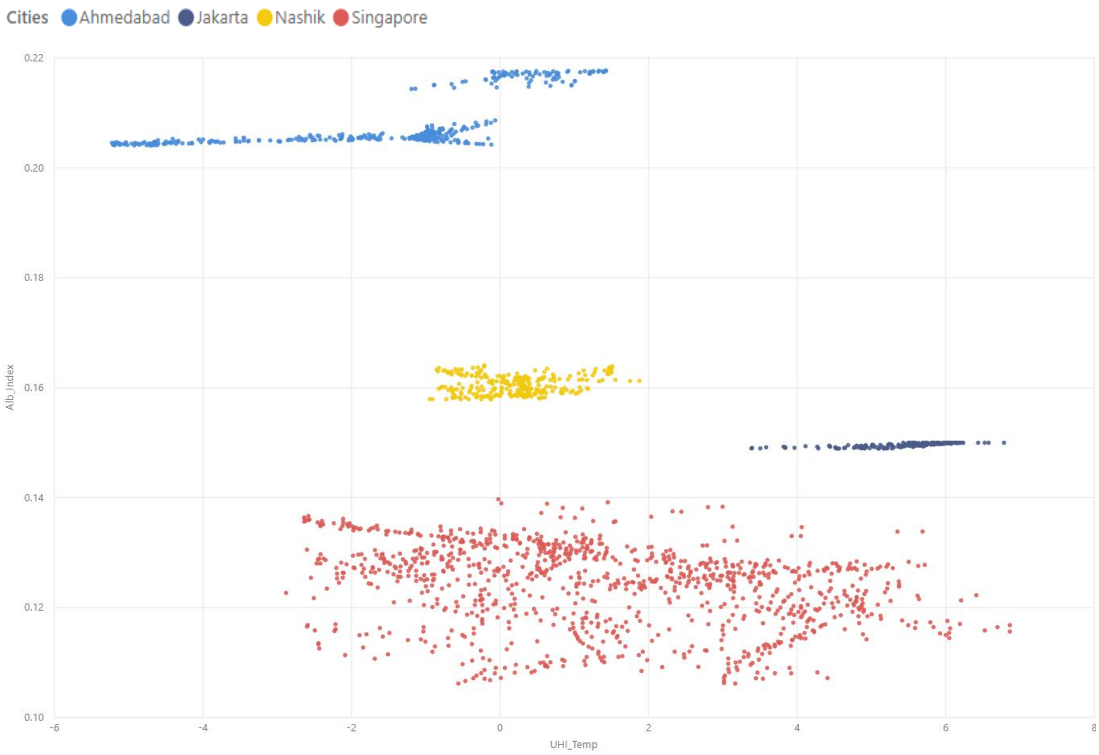
Our methodology to curate and resample Urban Heat Island is shown in the chart below.



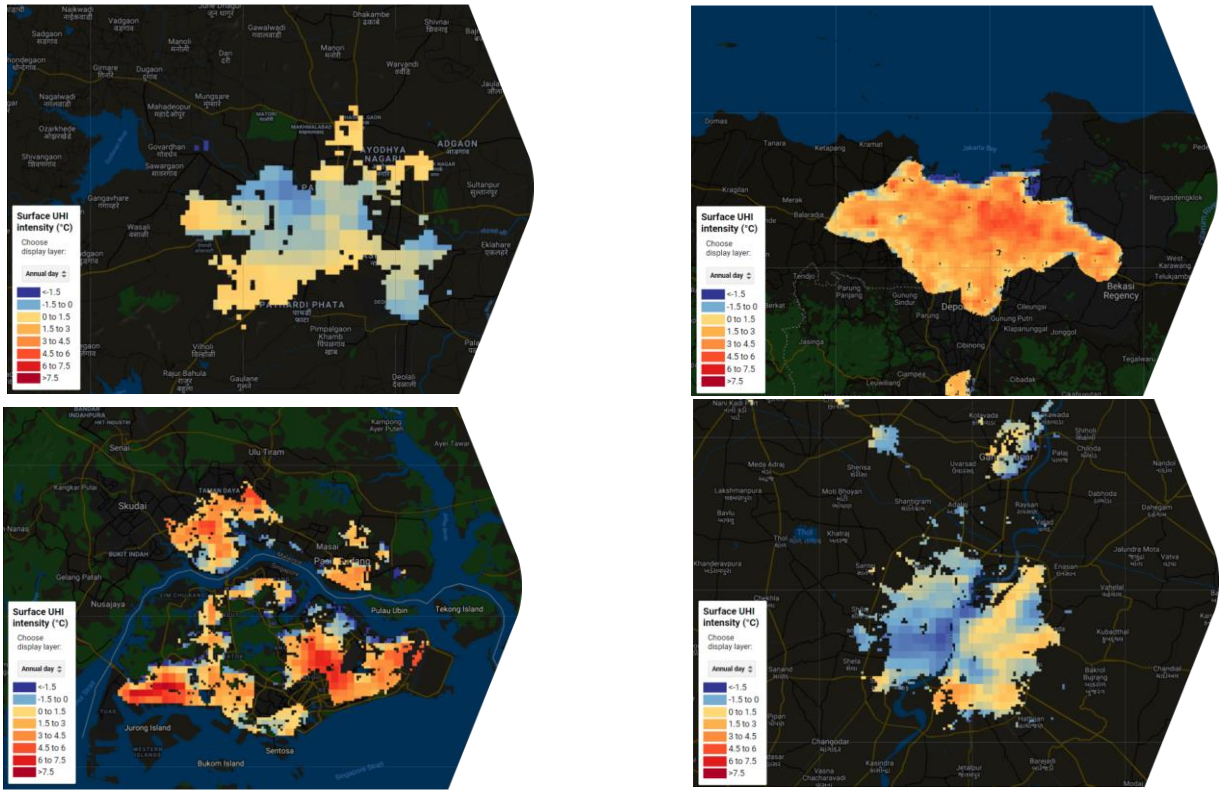
The same methodology was applied to the Alb_Index variable, with the caveat that the data obtained for this variable was from the ERA-5 Land hourly data, which is satellite based, and provides a consistent view of the evolution of land variables over several decades at an enhanced resolution. More about this data:

https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=overview

Although the resolution for Alb_Index data was resampled to our tessellate grids, the values that were collected were important to approximate and allow the comparison at the city level, rather than at the humanized 5-minute walk scale.



Albedo Indexes ("Y" axis) per cities, and its relationship to overall UHI temperature ("X" axis) contribution.



Images above: UHI temperature differentials for 4 urban clusters: Nashik (top left), Jakarta (top right), Singapore (bottom left), and Ahmedabad (bottom right)

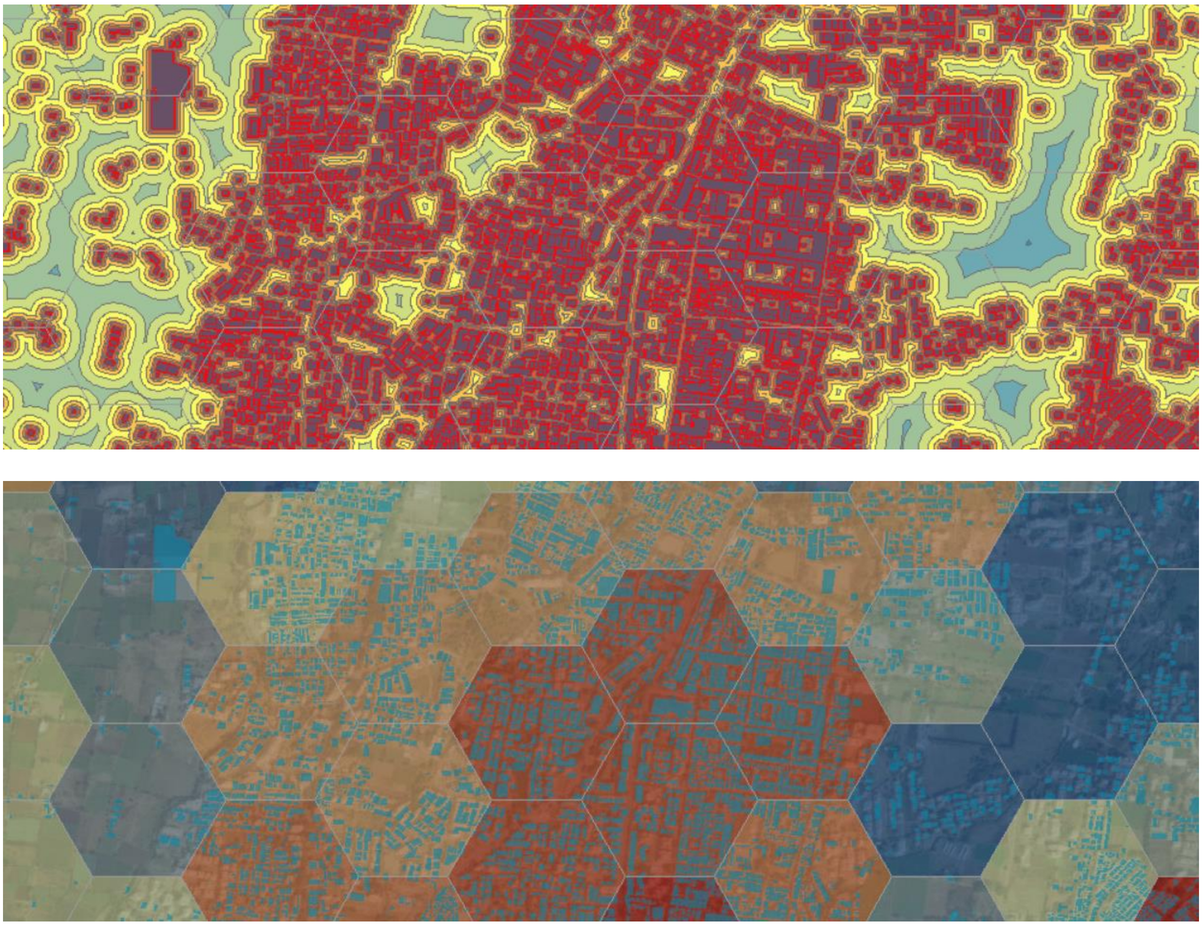
UHI temperature and Albedo data was obtained for the latest timeframes available. For UHI data, this was available for the year 2018, while for Albedo it was depending on the location, with latest data collected for 2020 and 2019 in most cases. All of these datasets were filtered to summertime months and summer daytime averages (hottest times, generally speaking).

URBAN MORPHOLOGY DATA

Land Use Diversity (LUDiv) was studied to quantify the amount of variety in land use within a walking distance. This variety measure is valuable to identify clusters of walkable neighborhoods. The statistical metric to derive a result was also based in the tessellate grid, computing the standard deviation of values in 5 categories of land use: commercial, residential, institutional/office, nature/green, and “all other”.

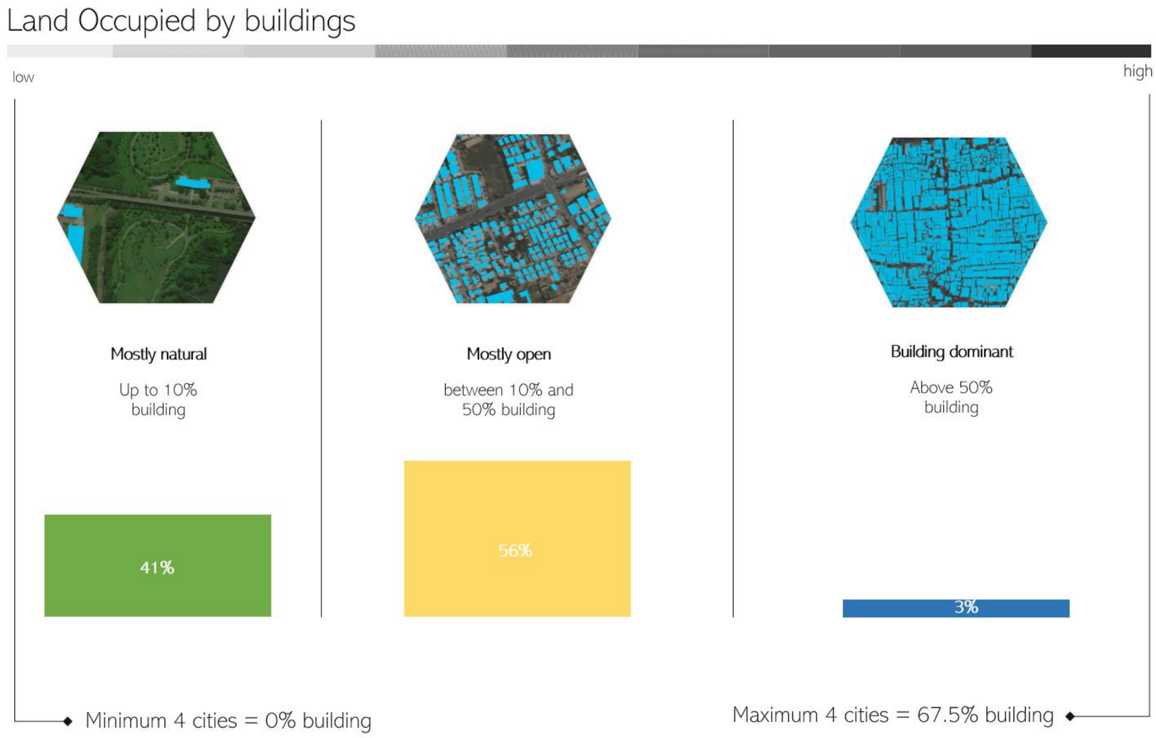
Building Compactness (BC) is a measure of clustering of buildings. This metric is derived from a statistical analysis of area calculations of multi ring buffers around building footprints. The methodology to calculate these values is described in this article by Julio Carrillo: https://parkhill.com/insights/Compact-Campuses/

The statistical measure of BC is comparable between tessellates (hexagon grid) as all hexagons are sized equally. This measure allowed us to compare data grids (hexagons) uniformly.



Processing proximity multiple ring buffers (top) to obtain values by tessellate grid (bottom). This measure was labeled "Building Compactness" (BC), and pictured in a scale red=high compactness, to blue=low compactness.

This measure was extremely useful, as it helped us understand that most areas in urban clusters are not building dominant, in fact, most Asian cities do not go above approximately 60% of building dominance (land occupied by building) per tessellate grid. Exceptionally high building dominance was encountered in Jakarta, with a maximum land occupation by building of 67.5%.

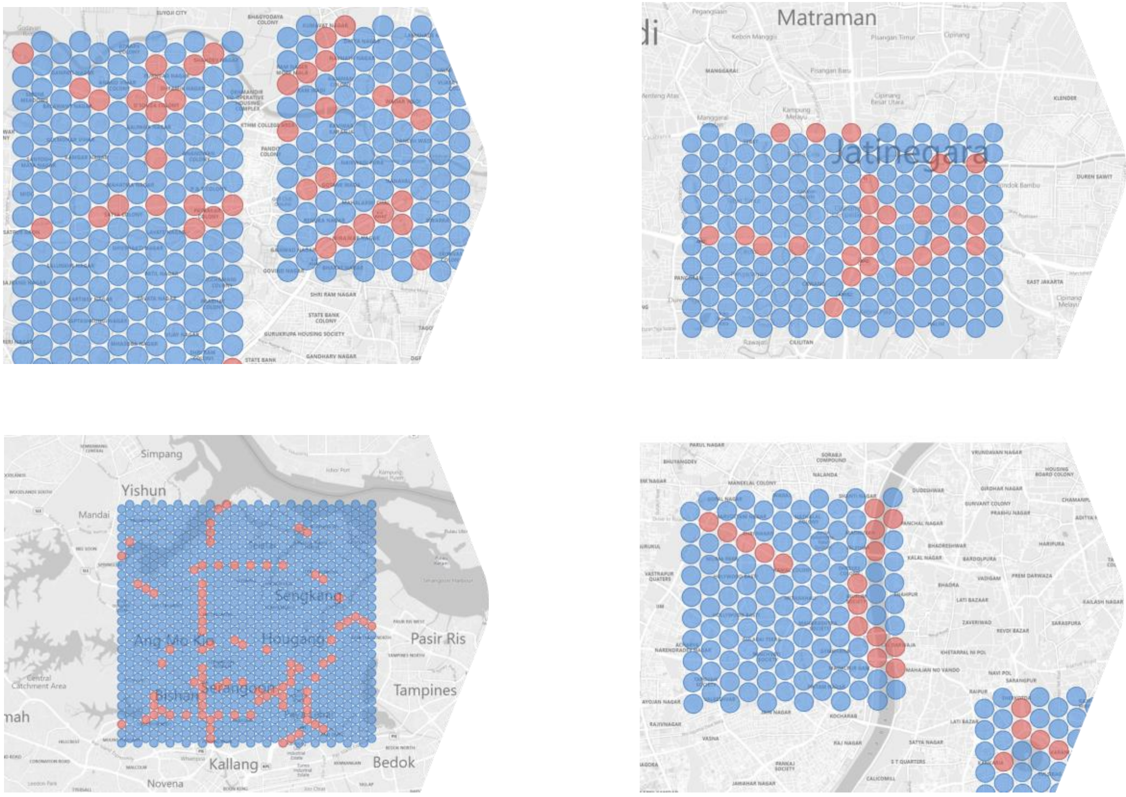


Land Occupied by Buildings -- On average, building footprints represent 20%-30% of all urban clusters. 97% of all data points were either "mostly open" or "mostly natural" morphologies. A maximum occupancy of land by building of 67.5% was encountered in Jakarta. Overall, for all asian cities in this study, 3% of tessellates were above the 50% threshold on building dominance.

HIGHWAY-DOMINANT FILTERING

With such a lower amount in average representing land consumed by buildings, our team deducted that most contribution to heat island must come from the spaces in between buildings (open space). Therefore, a next step in this research proposed the study of morphological spaces that are dominantly human-built, and with very low building presence. The idea was to filter out large areas within our cities that represent man-made infrastructure that do not show a high amount of integration with natural solution, such as highways, roads, or surface lots.

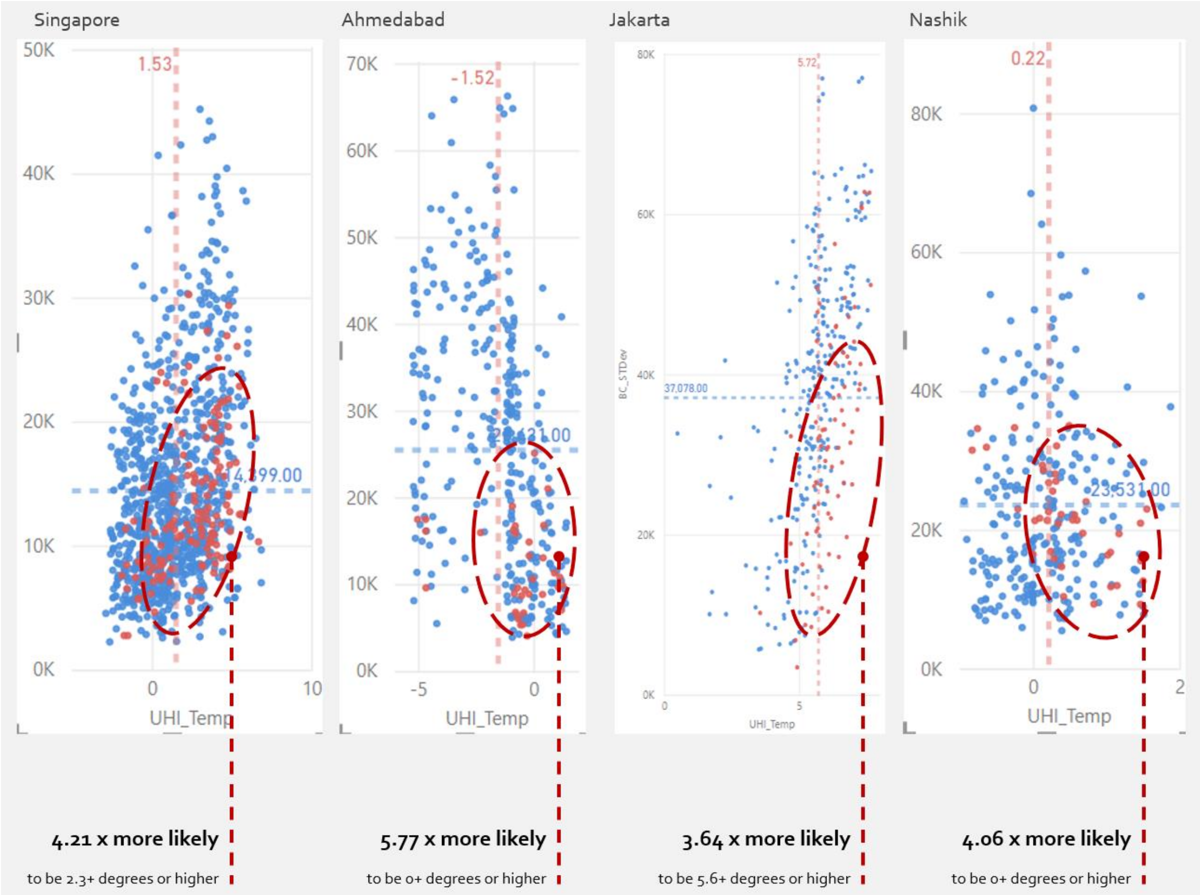
Given the morphology of cities, our team shifted its focus to quantify the contribution of open space with Urban heat island's temperatures. This new focus refers to highways/roads and surface parking lots. Our research team decided to filter out highway dominant tessellates to statistically quantify its contribution to UHI temperature increase.



Images above: Filtering highway-dominant areas for 4 urban clusters. Filtered tessellates pictured in red: Nashik (top left), Jakarta (top right), Singapore (bottom left), and Ahmedabad (bottom right)

Our filtering process and post evaluation derived that highway-dominant spaces are more likely to contribute to UHI temperature increase, in comparison to all other data points in the study.

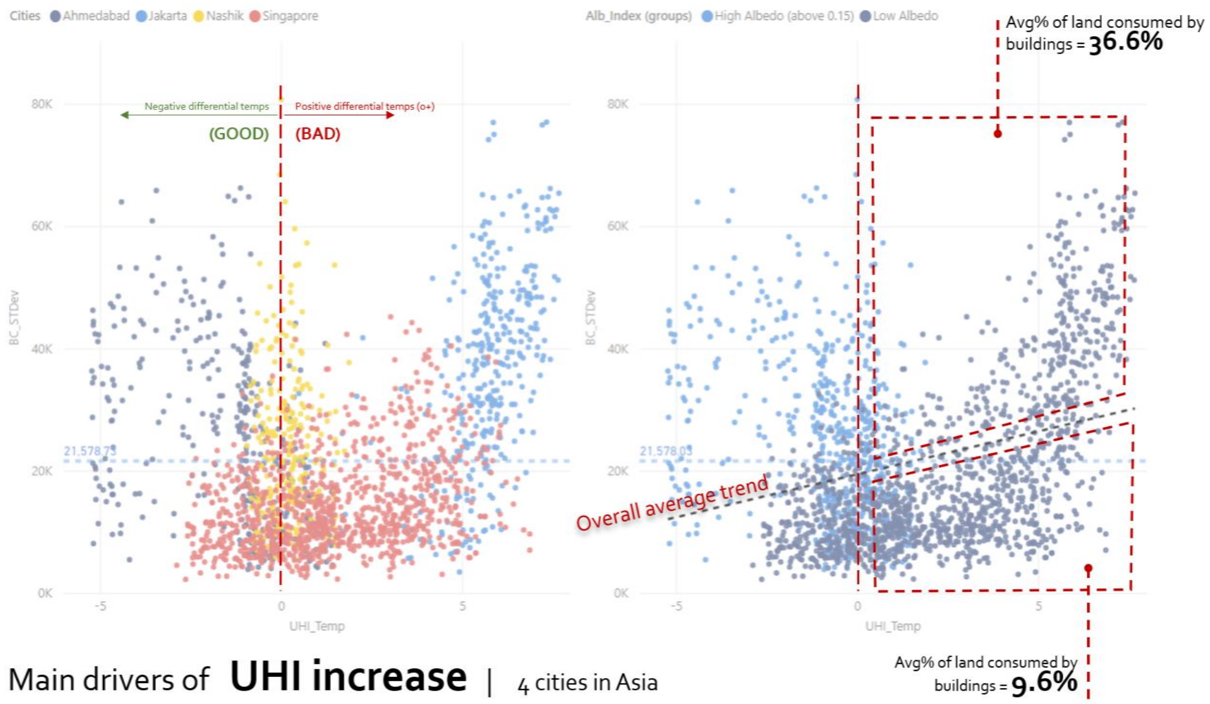
Results indicate that Singapore is 4.21 times more likely to experience 2.3+ degrees or higher. In Ahmedabad, there are 5.77 times more likely to have 0+ grades or higher. Finally, in Nashik there is a 4.06 times greater chance of having 0+ degrees or more. On the other hand, in Jakarta the chances of being 4.8+ degrees or more, are extremely high, which might also indicate a higher contribution of UHI temperature increase due to its high building compactness.



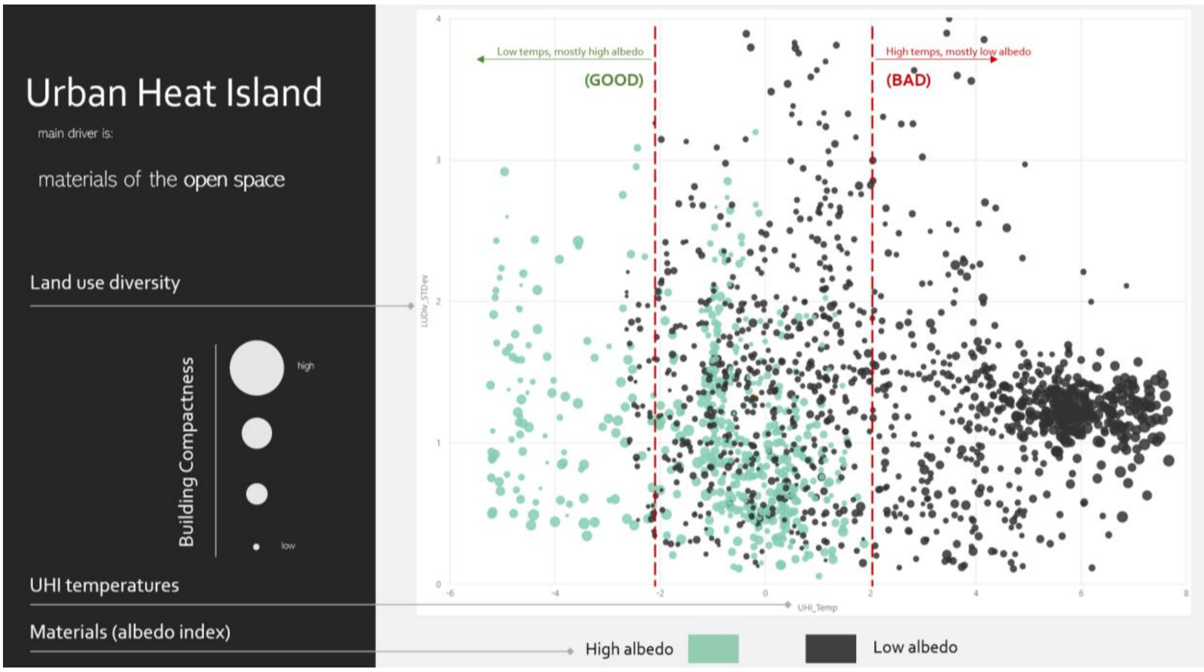
The segregation of highway dominant areas confirmed the increase likeability to UHI temperature increase in all of the 4 Asian cities.

CORRELATIONS & MAIN FINDINGS

Urban morphology of Asian cities is clear in terms of land occupied by buildings. This occupation brings to light that most areas in urban clusters are either roads and/or open space, which is highly correlated to Urban Heat Islands, additionally to the correlation with Building Compactness (BC). Most importantly, highway-dominant spaces are contributing the most to UHI temperature increase.

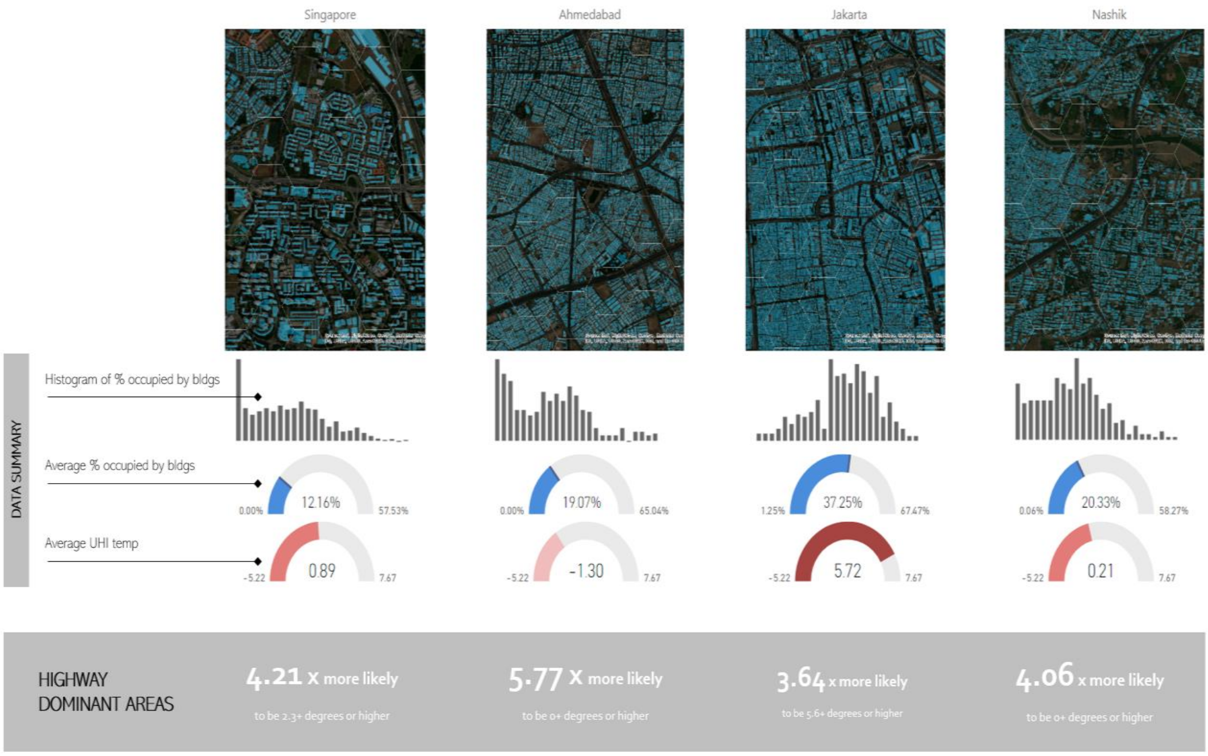


Materials of the open space are in direct correlation with the UHI temperature increase, so a stronger link to wide roads and highways are statistically proving those are likely the worst aspects of the built environment in terms of UHI.



The data summary below shows the morphology distribution of the 4 Asian cities in this study, in terms of land occupied by buildings and UHI temperatures.

The city of Singapore corresponds to the lowest average of building occupation with a 12.16% in a range between 0% and 57.53%. On the other hand, the city of Ahmedabad's average land occupied by buildings is 19.07% in a range between 0% and 65.04%. Jakarta presents the highest percentage of building occupancy in average, being 37.25% in a range between 1.25% and 67.47%. Finally, in Nashik this average value is 20.33% in a range between 0.06% and 58.27%.



Data summary for 4 Asian cities in terms of land occupation by buildings and Urban Heat Island temperatures for all data points in the analysis.

In terms of UHI temperatures, Jakarta has the highest value of differential temperature contribution, with a maximum differential of 7.67 degrees, while Nashik, Ahmedabad and Singapore have considerably less averages in differentials ranging from -1.30 degrees (Ahmedabad) to 0.89 degrees (Singapore). A negative differential in these values means that the algorithm for UHI values finds less contribution within the urban cluster compared to the outside surroundings. For more information on UHI calculation, refer to this methodology by Yale University:

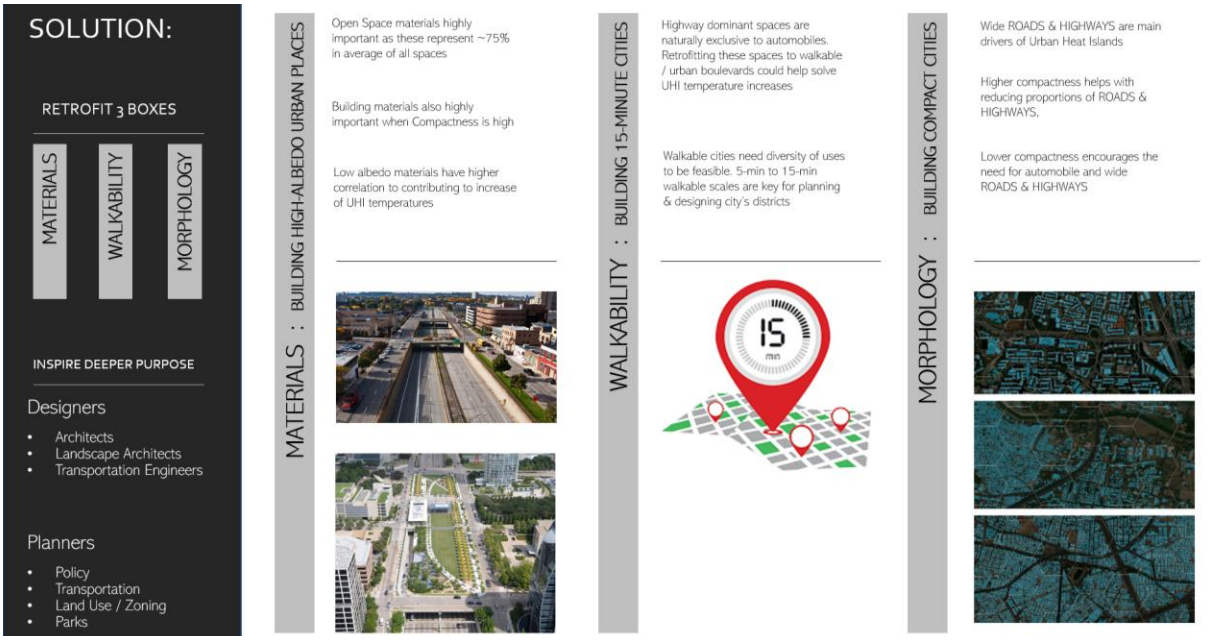
https://yceo.yale.edu/research/global-surface-uhi-explorer

With a clear deduction of open space as the main driver of UHI temperature increase, our team filtered highway dominant hexagons for all cities, to evaluate their likeability of their contribution. The result of this analysis derived that highway-dominant spaces are more likely to contribute to UHI temperature increase, in comparison to all other data points in the study.

SOLUTIONS AND NEXT STEPS FOR PLANNERS AND DESIGNERS OF THE BUILT ENVIRONMENT

This study reflects the urban data analysis of four Asian cities: Jakarta, Singapore, Ahmedabad and Nashik. Our analysis proposes 3 key aspects for solving UHI and climate change issues. These 3 solutions are categorized as actions related to:

- Materials
- Walkability
- Morphology patterns



Summary of key strategies and solutions to minimize UHI effects and take actionable steps towards positive improvement.

Regarding materials, it is recommended to build -and retrofit- areas for the creation of high-albedo urban places. Open space materials are very important, accounting for 75% on average of all open space in the city. Building materials also play a major role when compactness is high, so an intentional high-albedo and/or green roof strategies shall be implemented. In this study, it was found that low albedo materials have higher correlation to contributing to increase of UHI temperatures. High albedo urban places should explore the need of nature integration, not only in a physical way, but to also contribute to the health and culture of communities.

In terms of walkability, with the purpose of having 15-minute cities / neighborhoods, we need to pay special attention to dominant highway spaces and or wide roads, which today are naturally exclusive to automobiles. The reconversion of these spaces into walkable urban boulevards could help to solve the problem of rising UHI. On the same note, walkable cities need diversity of uses to be feasible and human-friendly. In this way, using 5-min to 15-min walkable scales are key when planning and designing neighborhoods / districts. Reducing the proportion of wide roads and highways, while at the same time offering a fair amount of diversity of uses, would be the appropriate strategy when planning and designing neighborhoods / districts.

In improving the morphology of cities, building compact cities is a solution. This is because greater compactness helps to reduce the proportions of roads and highways. On a similar note, a higher compactness will encourage the reduction of a need for cars and automobiles.

Finally, the data and conclusions found in this study will hopefully provide inspiration for future work of architects, landscape architects and transportation engineers. Through the design of urban projects, these recommendations and guidelines could be considered. Also, planners and designers should focus their studies and analysis on areas such as policy, transportation, land use/zoning and parks.

It is recommended that urban proposals be made considering these three key strategies, and the lessons learned based on the four Asian cities. It is up to us to generate more livable and walkable cities with better urban qualities.